

DEVELOPMENT OF RECEIVING EQUIPMENT  
FOR RECEPTION OF GROUND AND SKY-WAVE  
LORAN PULSES

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A THESIS

Submitted in partial fulfillment  
of the requirements for the Degree  
of Master of Science in Electrical Engineering

by

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## ACKNOWLEDGEMENT

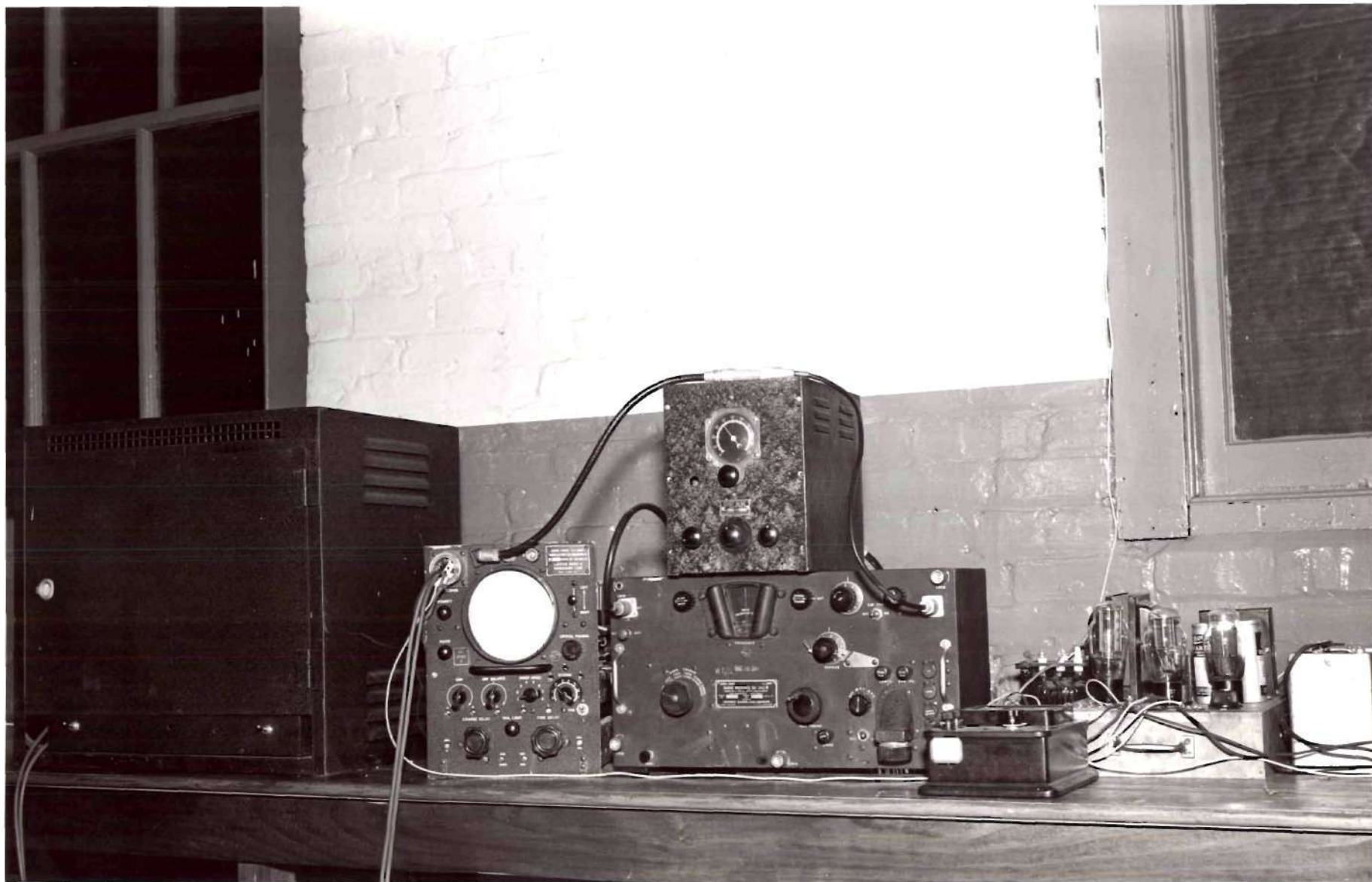
I wish to express my most sincere appreciation to Professor M. A. Honnel for his many practical suggestions that immeasurably aided the prosecution of this problem.

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Developed Equipment in Final Form

DEVELOPMENT OF RECEIVING EQUIPMENT  
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INTRODUCTION

During the war a great deal of attention and research was devoted to Loran<sup>1</sup>, a radio navigation aid. The basic principle in this system is the determination of the difference in time of arrival of radio frequency impulses sent in synchronism from two or more stations located a known distance apart. These signals have a fixed carrier frequency in the two-megacycle region and a pulse repetition rate varying between twenty-five and thirty-four cycles per second. Both the carrier frequency and the pulse repetition rate are assigned in such a manner as to identify uniquely each group of stations in the service area.

In spite of this precaution it was soon learned that reflections from the ionosphere were quite prominent and could be very confusing to an operator who expected to receive only the ground wave signal. Exhaustive

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<sup>1</sup>D. G. Fink, " The Loran System - Part I ",  
Electronics, November, 1945, pp. 94 - 99.



studies were made by J. A. Pierce in Bermuda<sup>2</sup> to determine what could be done. The results, fortuitously enough, showed that reflections from the E layer were so constant and dependable that they could be used for position calculation whenever the ground wave attenuation became too great. Only a correction factor relating sky and ground wave path lengths was needed for satisfactory results. When the E-layer reflection was employed together with the correction factor, the maximum Loran range of 710 miles was extended to a range of nearly 1400 miles.

Since the ionosphere played an important part in the operation of Loran equipment, it was decided that such equipment could easily be converted for use in studying the effects of the ionosphere on Loran pulses and could be indirectly used to study changes in the ionosphere itself.

This thesis deals with the development of receiving equipment for reception of ground and sky-wave Loran pulses. It discusses the equipment used, the modifications that were found necessary, and the technique used to obtain the results.

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<sup>2</sup>J. A. Pierce, "2-MC. Skywave Transmission ", Electronics, May, 1946, pp. 146 - 153.



## EQUIPMENT

Basically the equipment for this project consists of a preselector, a radio receiver, BC-342, a Loran indicator, ID 6B/APN-4, and a high and low voltage power supply arranged as shown in Fig. 1.

The indicator<sup>3</sup> is of a type that was mass produced for the use of the armed forces and performed creditably in the field. For this particular project certain alterations were necessary. In the first place, a Loran Receiver was not available. This necessitated the use of a different type receiver and required the construction of low and high voltage power supplies in order to operate the Indicator.

This particular set, designed for airplane use, employed a 400 cycle power supply in order to save weight in filters and transformers. The project, however, derived its power from 60 cycle commercial lines. Hence the 400 cycle filament transformer mounted on the indicator chassis was removed and a 60 cycle substitute transformer was installed on the high voltage supply chassis.

The radio receiver, Bc-342, is extensively used as a communications receiver by the United States Army. The band width of the R-F and I-F sections is broad enough to pass, with little distortion, the forty micro-

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<sup>3</sup>D. G. Fink, "Loran Receiver-Indicator", Electronics, December, 1945, pp. 110 - 115.

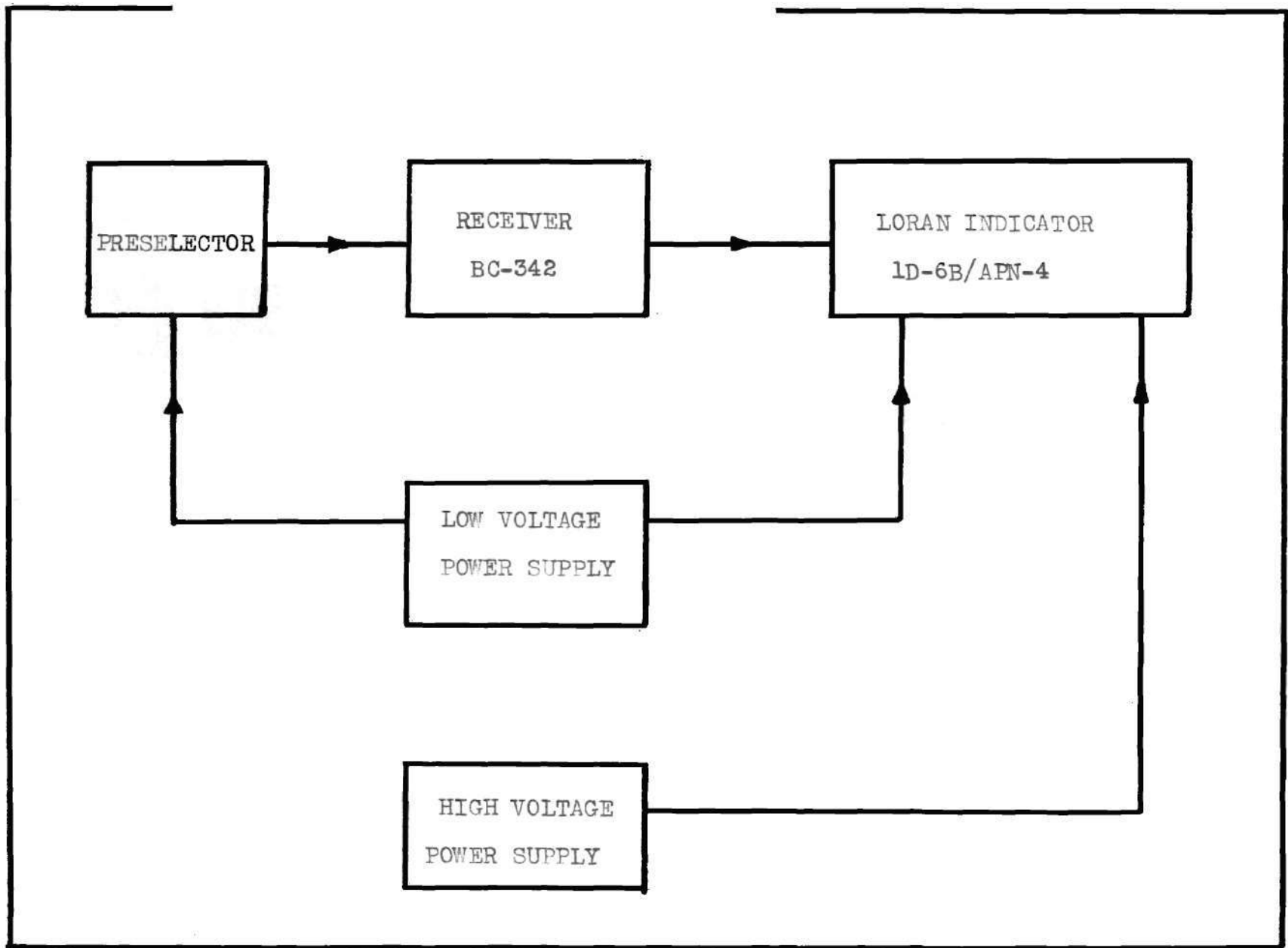


Figure 1. Block Diagram of Equipment

second pulse of the Loran signal. The relatively narrow bandwidth of the audio circuits caused the Loran signal to be distorted greatly. This necessitated the extraction of the desired signal from the grid of the first audio tube. This negative video pulse was fed directly to the Video Input jack of the Indicator.

The field strength at the project was found to be so very low that the use of a directive antenna with its attendant loss of gain as compared to a long wire antenna was prohibitive. In fact a two stage regenerative preselector was used to boost the strength of the signal before feeding it to the receiver. Since the normal antenna input circuit of the receiver had a low impedance, it was found necessary to feed the output of the preselector directly to the grid of the first R-F stage in the receiver.

## CIRCUIT FUNCTIONS

## A - Receiver and Preselector

Successive experimentation showed a long-wire antenna gave the best results. Consequently, an eighty-foot length of braided copper wire was hung as nearly vertical as possible. The antenna was connected directly to the two-stage preselector employing type 58 tubes.

The first stage was made regenerative by the addition of a 50,000 ohm potentiometer in series with the normal screen grid dropping resistor. Changing the value of resistance offered by the potentiometer varies the screen grid voltage and thus the  $g_m$  of the tube. Variations in  $g_m$  affect the magnitude and phase of the feed-back voltage. Correct adjustment of this feed-back voltage results in a gain much greater than can be achieved by a conventional R-F stage.

From the first stage of the preselector the signal passes through the conventional second stage of R-F amplification and goes directly to the grid of the first R-F stage in the receiver. The receiver employs two conventional R-F stages, a mixer, two I-F stages, and a combined detector and first audio stage to give the signal an over all amplification in the order of  $10^6$  from preselector antenna binding post to the grid of the

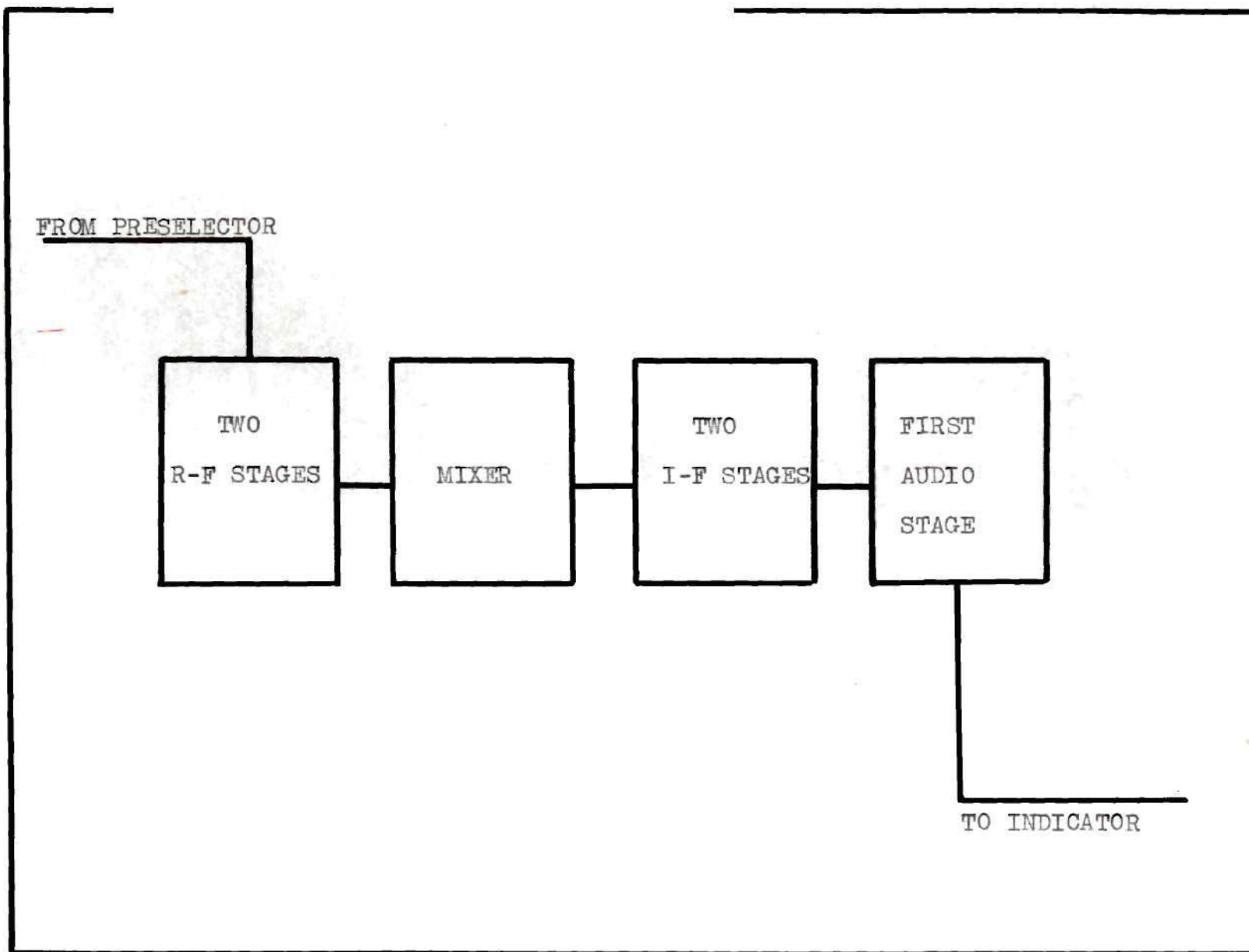


Figure 2. Block Diagram of Receiver



first audio stage. This output signal is fed directly to the Video Input jack on the Indicator.

#### B - Loran Indicator.

Essentially the Loran Indicator is an accurate timing device calibrated in ten, fifty, five hundred, and twenty-five hundred microsecond divisions. Its main function is to measure the relative time of arrival of a pair of Loran pulses.

##### (1) 100-KC. Oscillator Circuit

For its accurate calibration the Indicator depends on a 100-KC., crystal controlled, oscillator which functions as a master timing unit for all Indicator circuits. The Crystal Phasing control and the Left-Right control provide small changes of capacitance which result in slight frequency shifts of never more than plus or minus 35 cycles. A schematic diagram of the oscillator is shown in Fig. 4.

The output of the oscillator is a 100-KC. sine wave voltage, part of which is fed to a ten microsecond marker amplifier circuit where it is converted to sharp negative pulses recurring every ten microseconds. Part of the oscillator output is fed to a limiter tube which triggers the first counter circuit.



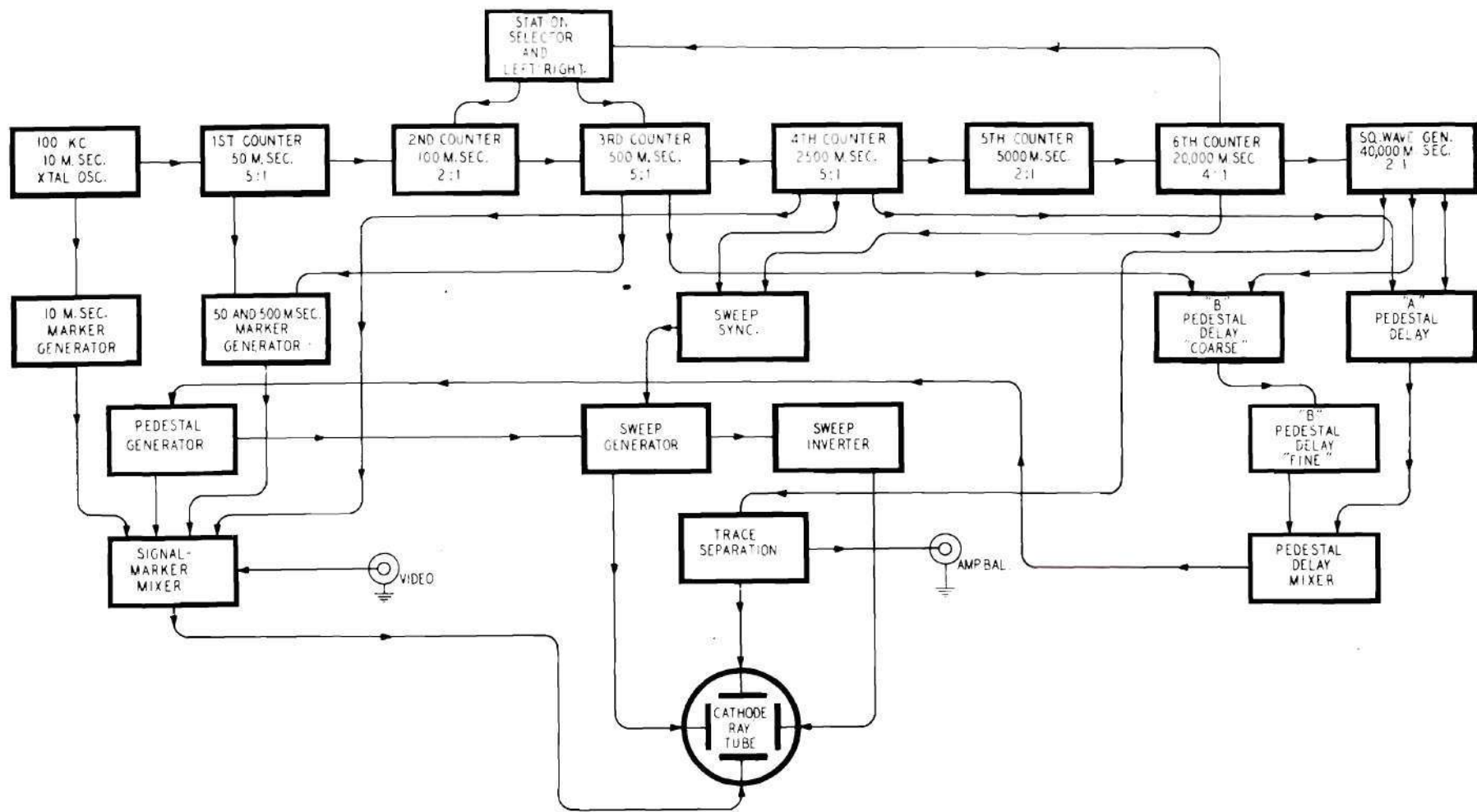


Figure 3. Indicator \*ID-6B/APN-4—Block Diagram

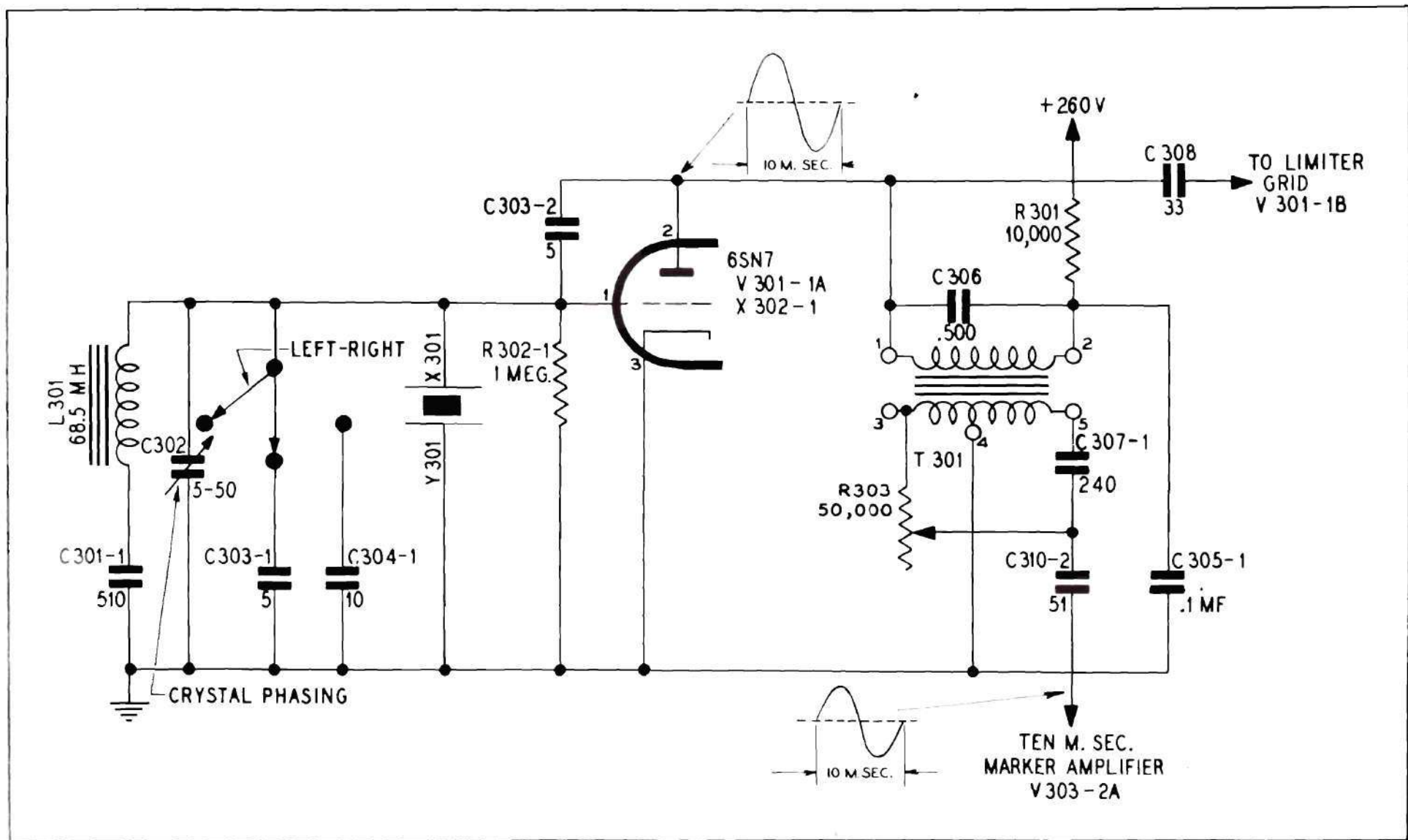


Figure 4. 100-Kilocycle Crystal Oscillator

## (2) Counter Circuits

Each of the six counters is a blocking oscillator.

A transformer is connected in the oscillator with the primary in the plate lead and the secondary in the grid lead of the same tube. In series with the transformer secondary is a large capacitor and a large resistance. As the tube conducts, the primary windings in the plate lead induce a very high positive voltage on the grid side of the secondary. Grid current flows, causing the series capacitor to take on a very high negative voltage. This voltage cuts the tube off. With no grid current the voltage begins to leak off the condenser, and after a specified time, dependent on the values of inductance, resistance, and capacitance of the circuit, the condenser has become discharged and will permit the tube to conduct again.

The first counter shown in Fig. 5 is adjusted to oscillate at a nominal frequency of 20-KC. It receives an initial triggering impulse from the 100-KC. oscillator which causes the tube first to conduct and then to block. The capacitance and resistance have been so adjusted that the voltage on the condenser, and hence on the grid, dies away so slowly that four triggering impulses from the oscillator limiter stage are applied to the counter grid with no effect. By the time the fifth trigger pulse has arrived, the negative voltage on the grid has fallen so

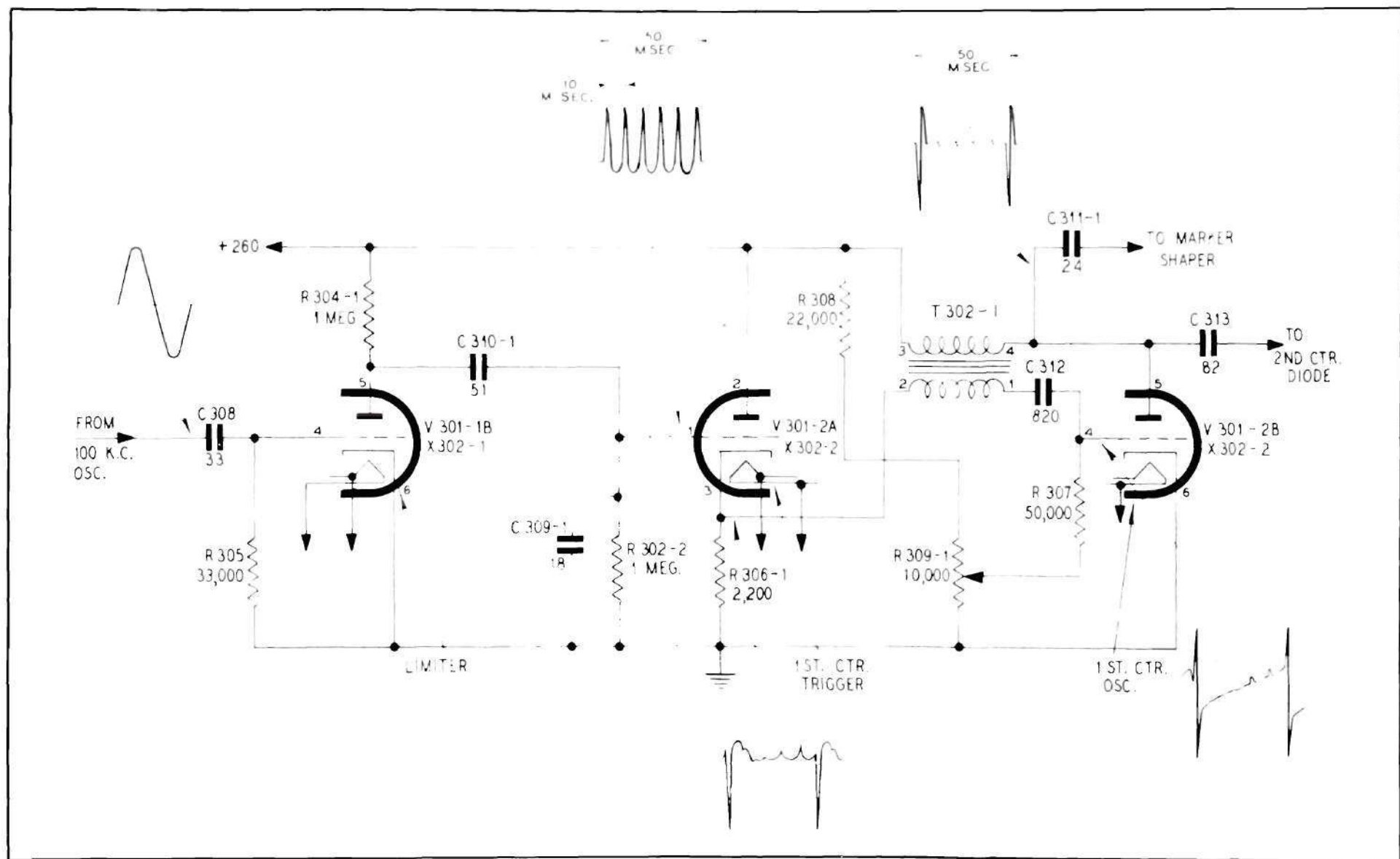


Figure 5. First-Counter Circuit



low that the trigger voltage raises the grid to a voltage such that the tube conducts and then blocks.

In this manner a frequency division of five to one is accomplished, giving output pulses that recur every fifty microseconds. Part of this output is fed to the fifty and five hundred microsecond marker shaper, and part is used to trigger the second counter.

The third counter divides the frequency of the second counter by five, thus producing 500-microsecond pulses. Part of the third counter output is used to terminate the B-"Coarse" delay action, part is used to trigger the fourth counter, and part is fed to the fifty and five hundred microsecond marker shaper.

The fourth counter, a five to one frequency divider, produces the 2500-microsecond markers. Part of the output goes to the fifth counter, part goes to trigger the sweep generator for Sweep Speed 8, and part goes to the video marker amplifier.

The fifth counter divides the fourth counter frequency by two, producing 5000microsecond pulses which are fed to the sixth counter.

The sixth counter is versatile. With the PRR switch in position H, the sixth counter acts as a three to one frequency divider producing a pulse recurrence rate of  $66 \frac{2}{3}$  cycles per second. With the PRR switch in position L, the counter acts as a four to one divider producing a pulse recurrence rate of fifty cycles per second. On Sweep Speed positions

1 and 7, the sixth counter triggers the sweep generator. Part of the sixth counter voltage is fed back to the second counter and to the third counter for left-right action and station selector action as described below.

### (3) Square-Wave Generator Circuit

Part of the output of the sixth counter controls the square-wave generator which divides the frequency of the sixth counter by two, thus producing square waves having a frequency of 25 and  $33 \frac{1}{3}$  cycles per second. The square-wave generator also provides trigger pulses for the pedestal delay circuits and serves as a source for trace separation voltages. The top of the square-wave is the A trace, the bottom is the B trace.

### (4) The Station Selector and the Left-Right Circuits

The Station Selector and Left-Right circuit feed-back part of the output of the sixth counter as either negative or positive pulses to the second and third counters, causing their conducting rate to change slightly, thus increasing or decreasing the recurrence rate of the sixth counter. Since the sixth counter output controls the trace recurrence rate, operation of the Station Selector and Left-Right circuits synchronizes the sweep circuits with the recurrence rate of the received signal.



### (5) The Pedestal Delay Circuits

The function of these vacuum tube circuits is to delay the appearance of the A and B pedestals on their respective traces until sometime after the start of each trace. The actions may be divided into four sections: the A-delay, the B-"Coarse" delay, the B-"Fine" delay, and the delay mixer.

The A-pedestal delay is initiated by the same pulse from the square-wave generator that starts the A-trace. After 1800 microseconds have elapsed, a triggering impulse from the fourth counter terminates the delay, allowing the A-pedestal to appear. This delay is fixed and cannot be adjusted.

The B-pedestal may appear at any time from 1200 to 12,500 microseconds after the start of the B-trace. Its appearance is controlled by the B-"Coarse" and B-"Fine" delay circuits. The B-"Coarse" delay is initiated by the output of the square-wave generator and is terminated by a pulse from the third counter. This delay action can be adjusted in 500-microsecond steps by means of three variable resistors mounted behind the front panel and entitled "Coarse", "Adj. 0", and "Adj. 10,000".

The B "Fine" delay is triggered by a pulse from the B "Coarse" delay circuit. It is continuously variable





from 200 to 700 microseconds by means of variable resistors mounted behind the front panel and entitled "Fine", "Adj. 200", and "Adj. 700".

#### (6) The Delay Mixer Circuits

The Delay Mixer receives the output from the A-delay and the B-delay circuits. It inverts and shapes these pulses to trigger the pedestal generator.

#### (7) The Pedestal Generator Circuits

The pedestal generator, a multivibrator, delivers positive rectangular pulses of either 250 or 750 microseconds duration. The duration is controlled by the plate voltage of the generator and the values of grid resistance inserted by the Sweep Speed control switch. Part of the pedestal generator output is fed to the pedestal section of the marker mixer tube and thence goes to the Cathode Ray Tube. Part of the output of the pedestal generator triggers the sweep generator in positions "2", "3", "4", "5", and "6", causing the trace duration to have the same duration as the pedestal. This permits the traces to depict only that portion of the signal which is on top of the pedestals.

#### (8) The Signal and Marker Mixer Circuits

The Signal and Marker Mixer circuits feed to the

vertical deflection plates of the Cathode Ray Tube the following signals: the video pulses from the receiver, the pedestals from the pedestal generator, and the ten, fifty, five-hundred, and twenty-five hundred microsecond markers.

The 10-microsecond signals which originate in the 100-KC. oscillator are shaped by the 10-microsecond generator. They then pass to the mixer tube and appear as upward deflections on the trace.

The fifty microsecond markers obtained at the output of the first counter are shaped by the marker shaper tube. They are then fed to the mixer tube and appear as downward deflections of the trace.

The 500-microsecond markers which are developed by the third counter are shaped in the marker shaper circuit. They are fed to the mixer tube and appear as downward deflections of the trace.

The 2500-microsecond markers are developed by the fourth counter. They are fed to the mixer and appear as both upward and downward deflections.

#### (9) The Sweep Generator Circuit

The sweep generator produces a linear sawtooth voltage with the aid of the sweep input-leveler, the sweep sync, and the sweep inverter circuits. On Sweep Speed positions "1" and "7" triggering voltages from

the sixth counter are properly shaped by the sweep input sync tube and fed to the sweep generator. On positions "2", "3", "4", "5", and "6", the generator is started and stopped by pulses from the pedestal generator. On position "8", the generator is triggered by the output of the fourth counter.

#### (10) The Sweep Inverter Circuit

Part of the sweep generator output is fed to the sweep inverter. Thus the output of the generator and of the inverter provide a push-pull voltage which is fed to opposite horizontal deflection plates of the Cathode Ray Tube to provide a linear, horizontal sweep.

## C - Power Supplies

A conventional voltage-regulated power supply which gives an output of 260 volts D.C. at 150 milliamperes was constructed to supply plate voltage for the preselector tubes and the indicator tubes. It consists of a 5Z3 rectifier, a 6SJ7 controlling a pair of 2A3's in parallel, and a standard L-C filter.

The cathode ray tube requires a potential of plus 1450 volts between its anode and ground and requires minus 1250 volts between its cathode and ground. To supply this voltage, a transformer with a 115-volt primary and 3000-volt secondary, center tapped, was used. Between one side of the secondary and the center tap a positive voltage was developed by a 2 X 2 rectifier and a one section R-C filter. Between the other side and the center tap a negative voltage was developed by a 2 X 2 rectifier and a one section R-C filter.



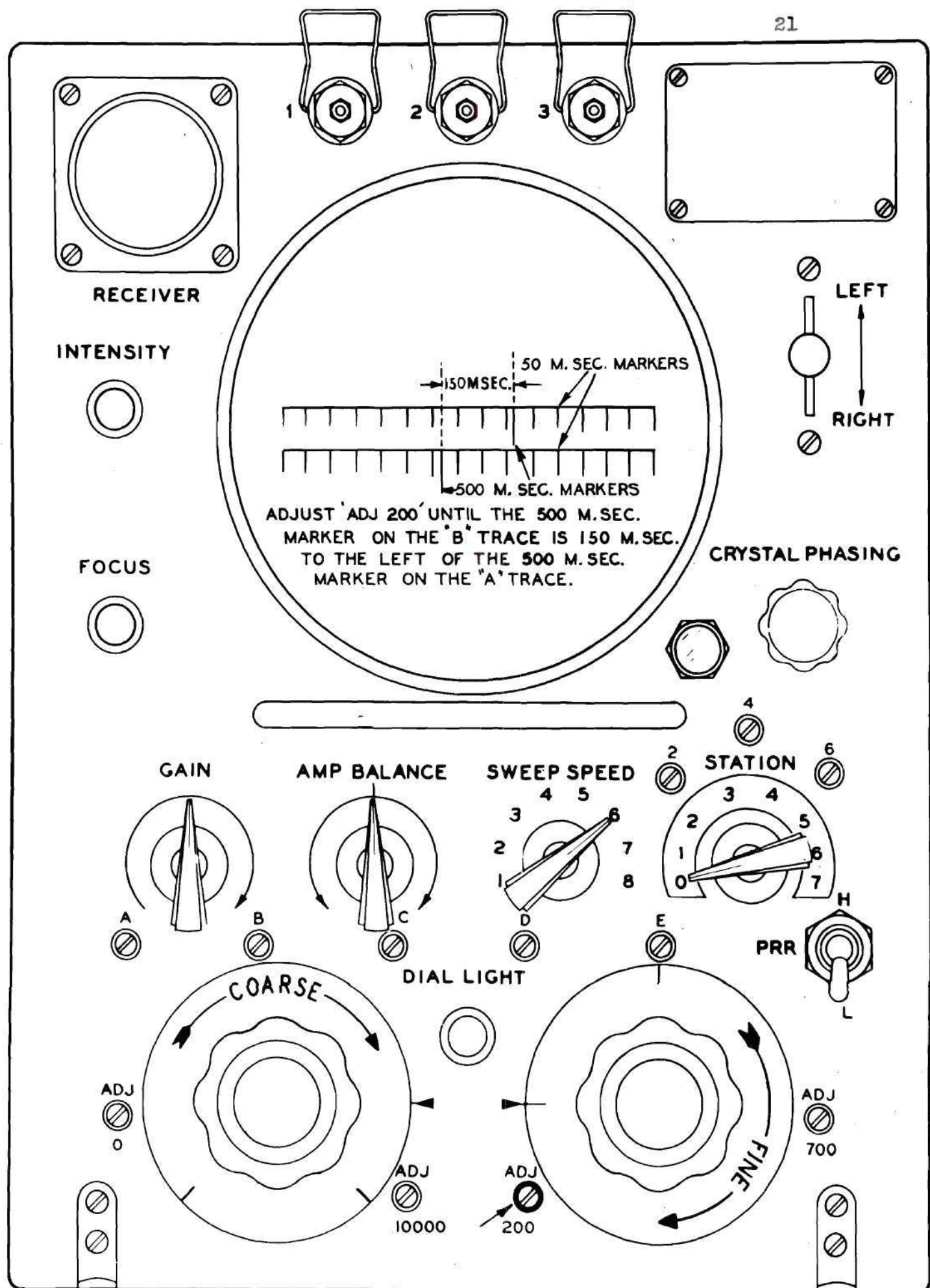


Figure 7. Diagram of Indicator Panel

## PRELIMINARY ADJUSTMENTS

Since all the indicator circuits are interdependent, it can be understood that the alignment procedure should be precise and sequential in order to obtain satisfactory results. The procedure outlined below gives the best alignment in the shortest time.

A - The set should be turned on and allowed to warm up for several minutes so that circuit functions have time to become stabilized.

### B - Counter Circuit Adjustment

(1) Turn the station selector switch to "0" and the Sweep Speed switch to "5". A pattern similar to Fig. 8 should appear on the indicator screen. Hereafter the top trace will be called A-trace, the bottom will be called B-trace. Adjust the Intensity and Focus controls until the proper definition of pattern is obtained. Sharp upward deflections, 10-microsecond markers, and longer downward deflections, 50-microsecond markers, should appear on each trace. Screw-driver adjustment "A" should be rotated until there are exactly four 10-microsecond markers between each pair of 50-microsecond markers. It should be noted that on adjustment "A" and all other variable controls in the indicator a mid-setting position can be found that will

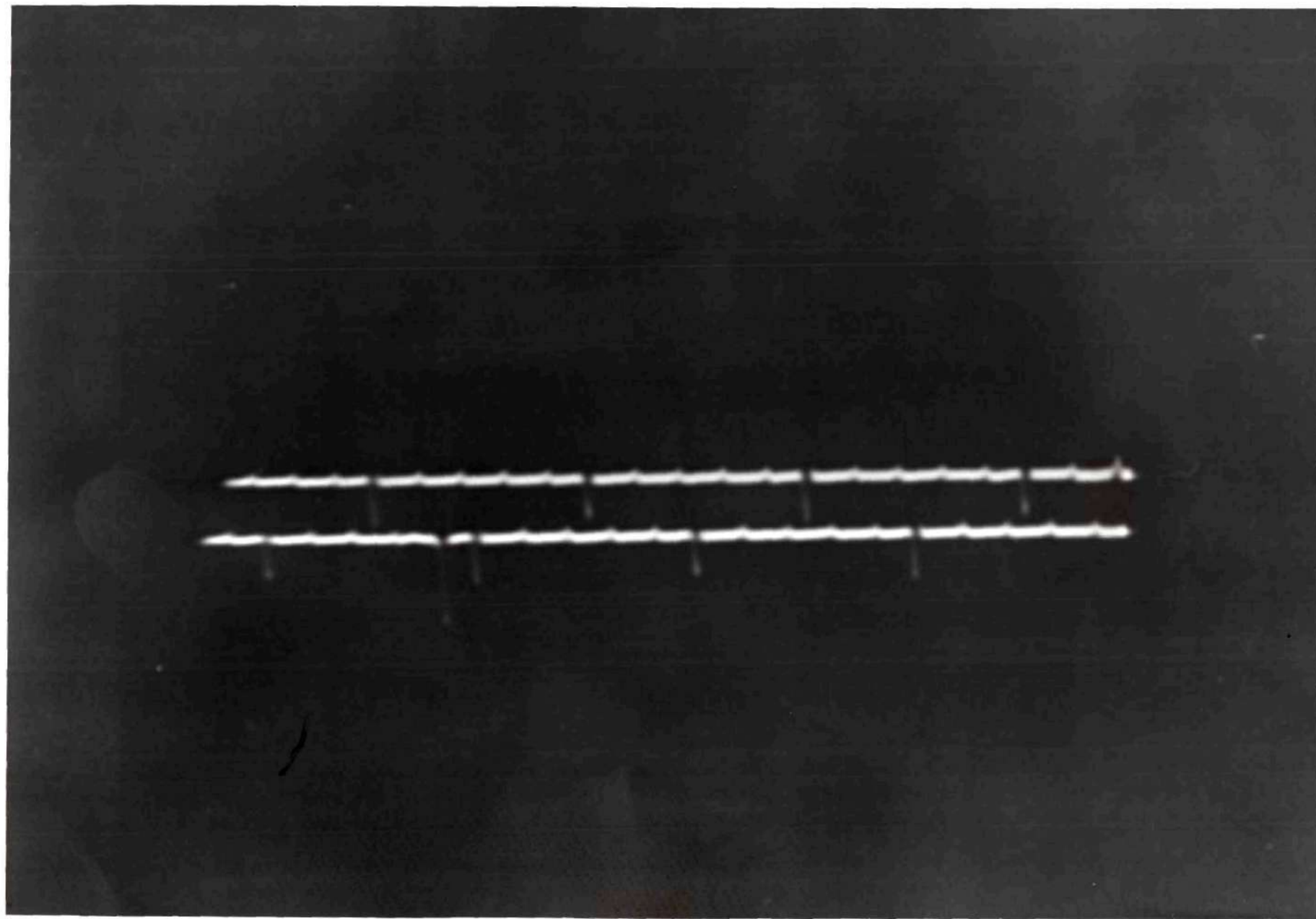


Figure 8. Oscilloscope Pattern - Sweep Speed Position "5"



produce the desired results. These controls should never be left at the first position that gives the correct pattern. Rather they should be tuned carefully as possible to the center range.

(2) Next turn the Sweep-Speed switch to position "6". Long downward deflections, 500-microsecond markers, and short downward deflections, 50-microsecond markers, should appear, as shown in Fig. 9. The Fine Control should be rotated until there are two 500-microsecond markers on the B-trace. Then adjustment "B" should be turned until there are ten 50-microsecond spaces between the pair of 500-microsecond markers. It will be noted that the 500-microsecond markers do not coincide with the tenth 50-microsecond marker. This is normal and does not result from misalignment.

(3) Turn Sweep-Speed switch to position "7" and the PRR Switch to "L". Pedestal pulses should appear on each trace together with 2500-microsecond markers, deflections that extend above and below the trace. In addition the 50 and 500-microsecond markers should appear. Screwdriver adjustment "C" should be turned until four 500-microsecond markers appear between a pair of 2500-microsecond markers. Although the 50 and 500-microsecond

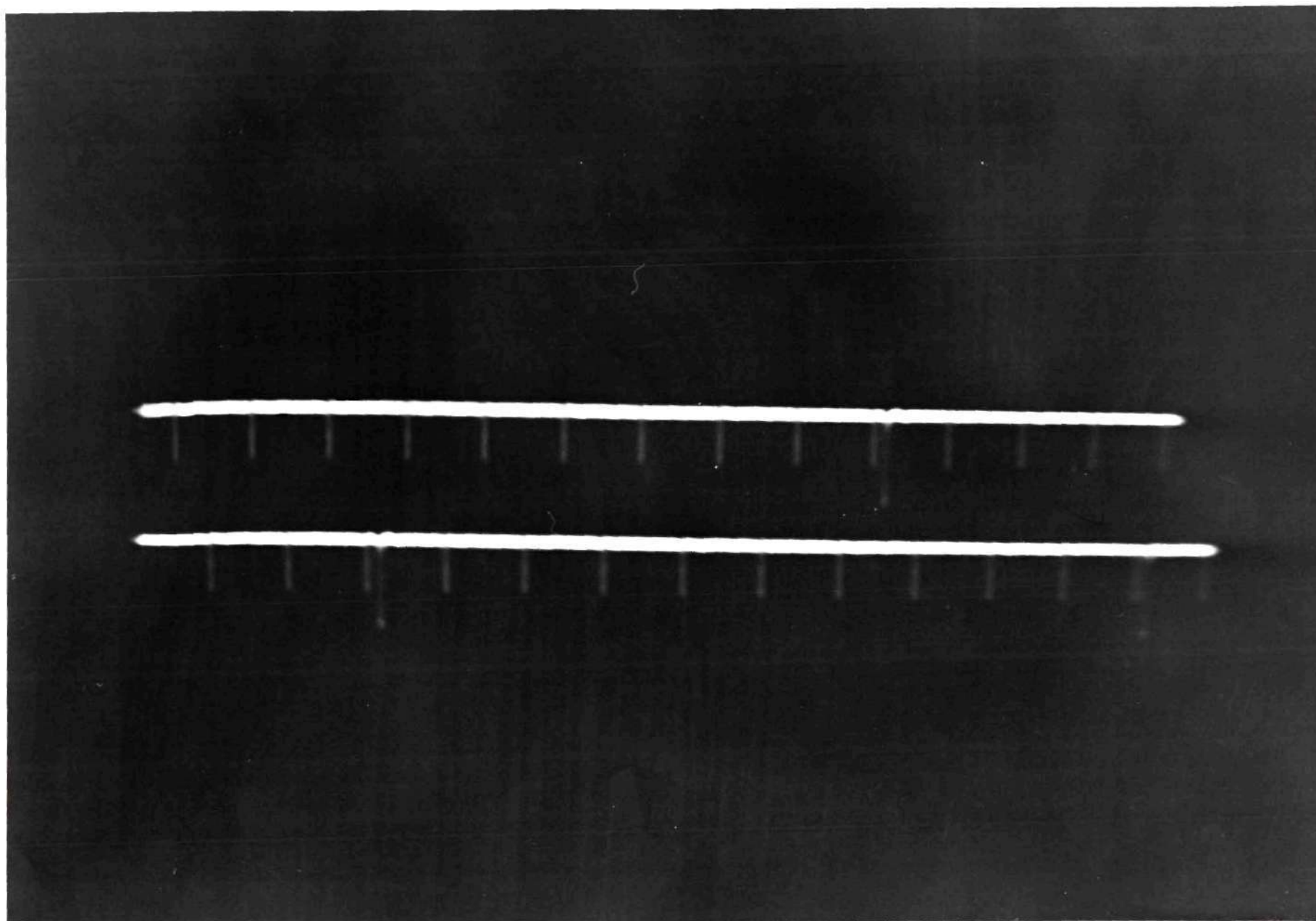


Figure 9. Oscilloscope Pattern - Sweep Speed Position "6"

markers do not appear clearly in Fig. 10, they are distinctly visible on the Cathode Ray Tube screen.

(4) Keeping Sweep Speed in "7" and PRR in "L", turn adjustment "D" until there are exactly eight 2500-microsecond markers in each trace. It will be noted that the eighth 2500-microsecond marker ends the trace.

(5) Keep Sweep Speed on "7", but change PRR to "H". Turn "E" until six 2500-microsecond markers appear on each trace. The trace now ends with the sixth 2500-microsecond marker as is shown in Fig. 10. The 500-microsecond markers which are plainly visible to the eye were not caught by the camera in Fig. 10.

#### C - Station Selector Adjustments

These adjustments provide for the synchronization of trace repetition rates with any one of sixteen different received signal pulse repetition rates and must be made with non-metallic screwdrivers.

(1) Turn Sweep Speed to position "8" and Station Selector to "0". On the screen a stair-step pattern should appear. If this particular configuration is not achieved, check the accuracy of the counter circuit adjustments.



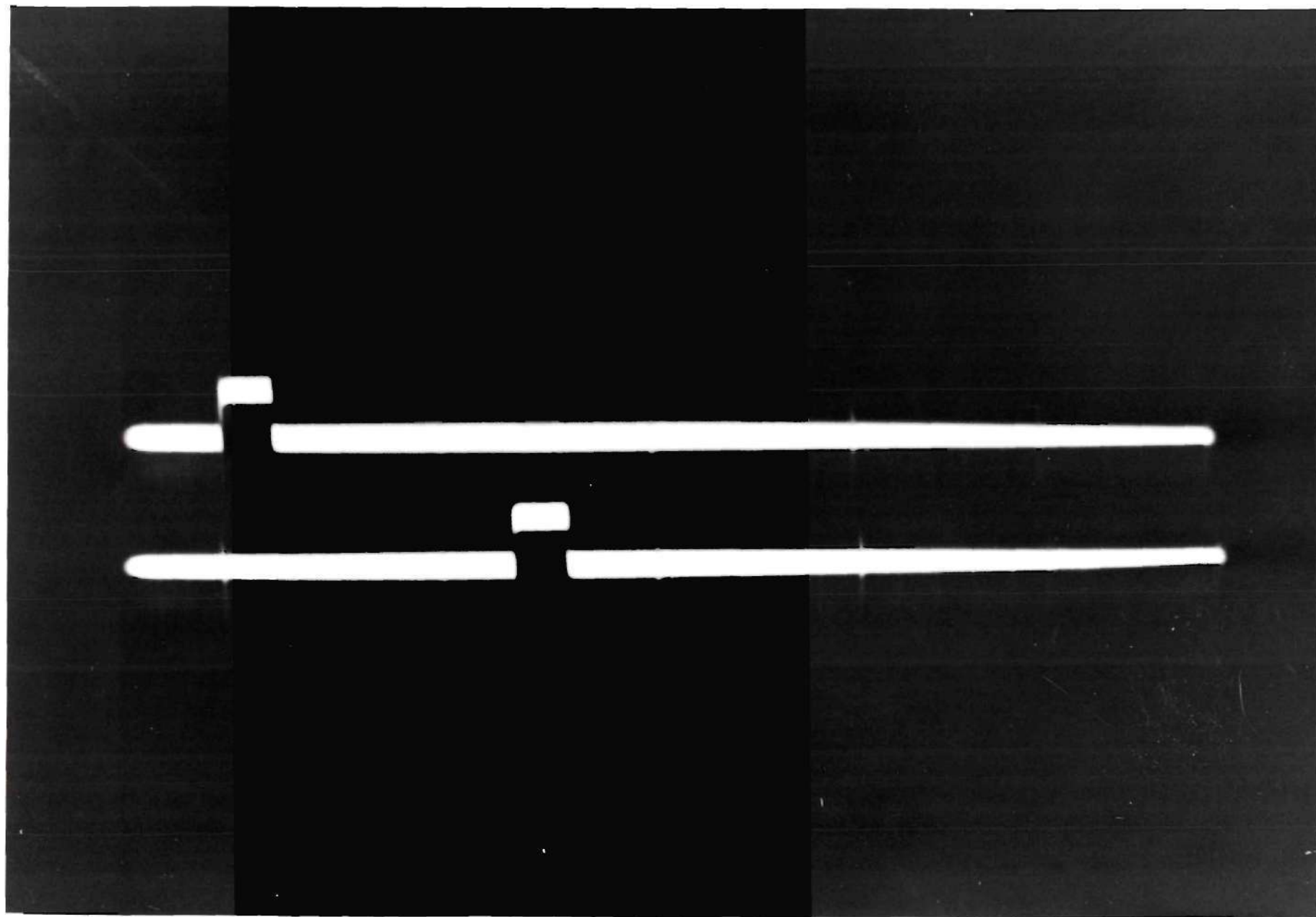


Figure 10. Oscilloscope Pattern - Sweep Speed Position "7"

The repetition rate in position "0" is the basic trace repetition rate of the indicator and no special adjustment is needed.

(2) Turn the Station Selector to position "1".

The pattern of part (1) called "Y" will have to its left a less brilliant counterpart, "X". If the Station Selector circuits are working properly, "X" and "Y" are in horizontal alignment. No adjustment is required for Station "1". (See Fig. 11.)

(3) Turn the Station Selector to position "2".

"X" has been displaced farther to the left of "Y". Correct horizontal alignment is secured by adjusting a screwdriver control, "2", above and to the left of the Station Selector switch.

(4) Turn to Station Selector position "3". If position "2" has been correctly adjusted, the "X" and "Y" patterns will be horizontally aligned; however, "X" will have been farther displaced to the left of "Y".

(5) Turn to Station Selector position "4". Initial installation adjustment is made by centering screwdriver adjustment "A" and bringing "X" and "Y" into horizontal alignment by turning R-329, the feed-back voltage control,

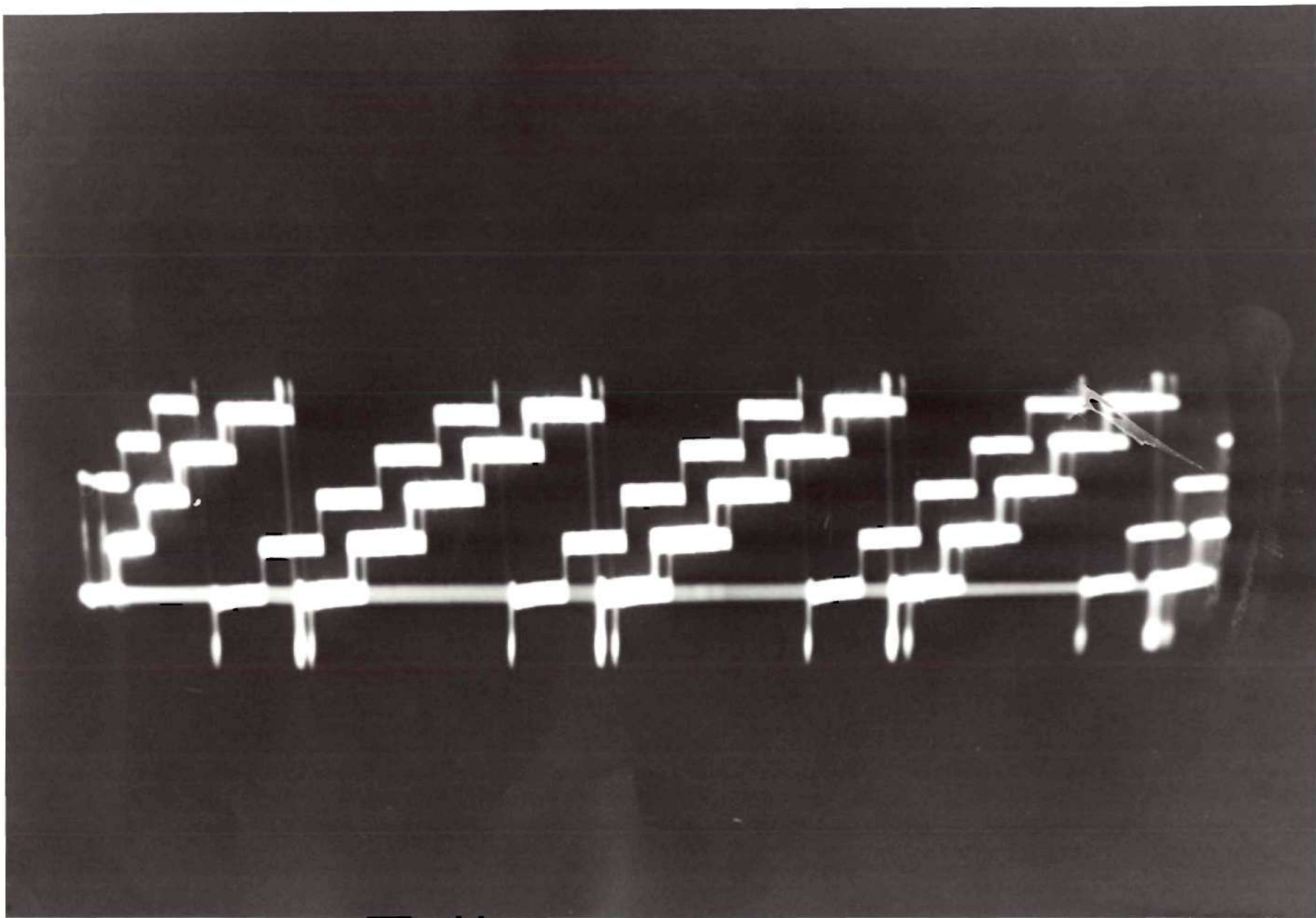


Figure 11. Oscilloscope Pattern - Sweep Speed Position "8"

located inside the outer case on the lower left side of the chassis. Subsequent adjustment of position "4" does not require entering the case. Merely changing the adjustment "4" will suffice.

(6) Turn to position "5". If "4" has been adjusted properly, "X" will have been displaced further but will be horizontally aligned with "Y".

(7) Turn to position "6". Adjust screwdriver control "6" until "X" and "Y" are aligned.

(8) Turn to "7". If "6" has been correctly adjusted, "7" will also be in correct adjustment.

#### D - Coarse and Fine Adjustment

##### (1) Fine Adjustment, "Adj. 200"

Turn the Sweep Speed control to position "6", the "Coarse" control to the center of its mechanical range, and the "Fine" control as far counter clockwise as it will go. Then turn "Adj. 200" to the center of its mechanical range. Next move it slightly to the right or left until the first setting is reached where the 500-microsecond marker on the B-trace is exactly 150-microseconds to the



left of the 500-microsecond marker on the A-trace.

(2) Fine Adjustment, "Adj. 700"

Leaving Sweep Speed in position "6" and "Coarse" in its center position, turn the "Fine" control fully clockwise. Then adjust "Adj. 700" until the 500-microsecond marker on the B-trace is exactly 250-microseconds to the right of the 500-microsecond marker on the A-trace.

Re-adjust slightly "Adj. 200" and "Adj. 700" to eliminate any interaction effects.

(3) Coarse Adjustment

Turn Sweep Speed to position "7" and rotate both "Coarse" and "Fine" controls fully counterclockwise. Trim "Adj. 0" until the right edge of B-pedestal is directly beneath the left edge of A-pedestal. Rotate "Coarse" control fully clockwise and trim "Adj. 10,000" until the left edge of the B-pedestal is 200-microseconds to the right of the fifth 2,500-microsecond marker on the B-trace. The PRR switch is in position "L" for this adjustment.

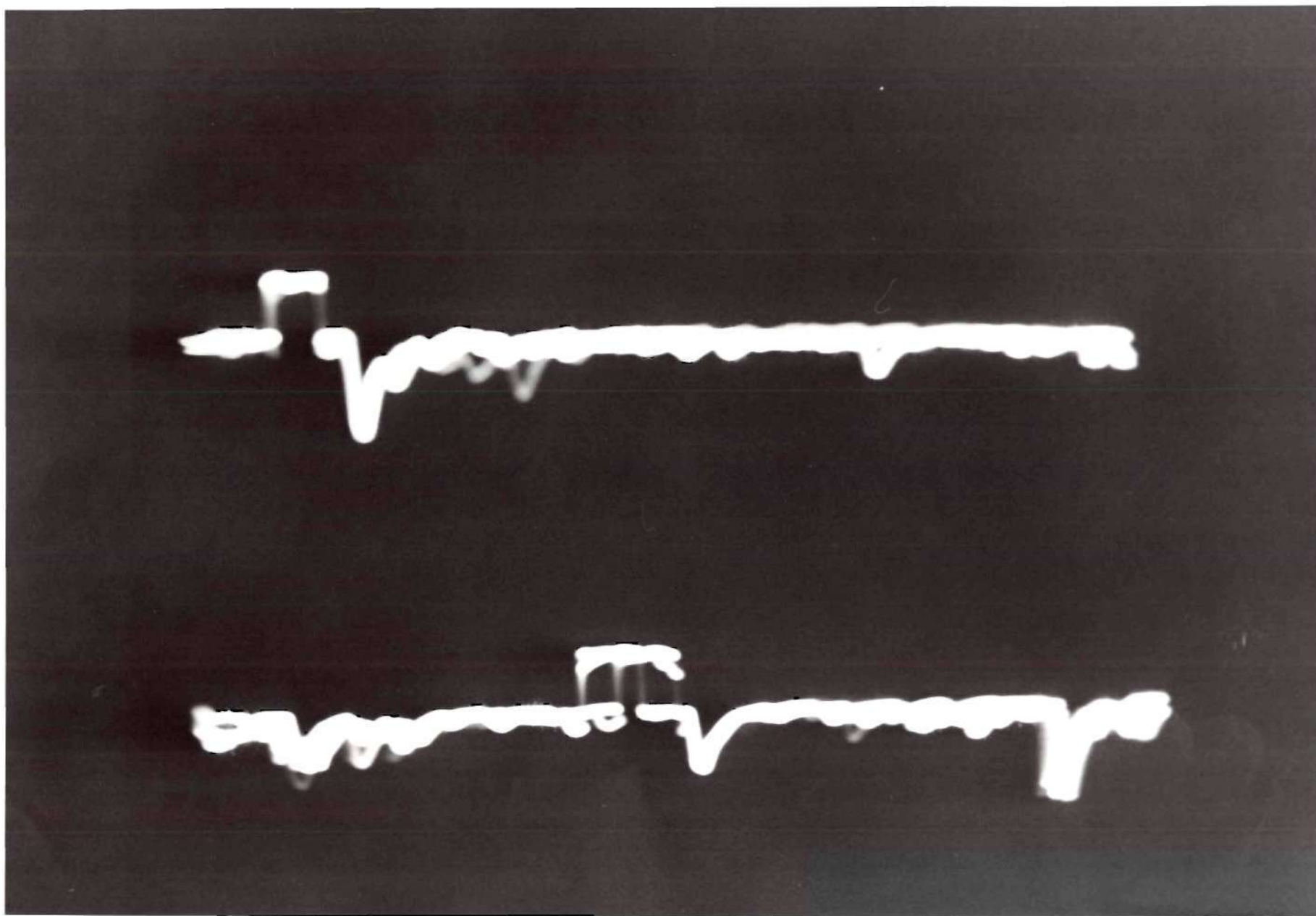


Figure 12. Oscilloscope Pattern - Sweep Speed Position "1"

## OPERATING PROCEDURE

After all the preliminary adjustments have been made on the Indicator, turn on the receiver and the preselector. Set the preselector band change switch in position "1", the main tuning dial at "36", and the regeneration control at its minimum setting, fully counter clockwise. Next turn on the receiver and tune to 1.95 megacycles. Set the indicator Sweep Speed switch in position "1".

As the receiver and preselector warm up, incoming signals should make their appearance known by downward deflection on the A and B traces as shown in Fig. 12. Careful adjustment of the regeneration control of the preselector in conjunction with the main tuning controls on both the receiver and the preselector should bring the pips to the desired size. The proper setting of the Station Selector switch will cause the signal to remain in one position on the screen. If the signals drift slightly, the Crystal Phasing knob can be adjusted to eliminate the drift.

When the object of the experiment is to determine the effect of the ionosphere on the Loran pulses, the Sweep Speed should be left in position "1". This gives a sweep duration of about 20,000 microseconds to the A-trace and to the B-trace. If the PRR switch is in position



H, the sweep duration is about 14,300 microseconds for the A-trace and for the B-trace.

At this point it should be noted that each Loran signal is transmitted by a station group, consisting of a master and a slave station, operating on the same frequency and having the same pulse recurrence rate. The signal from the master station is received by the slave station, delayed by a network, then allowed to trigger the slave station. The delay given by the network is adjustable in order that the total delay due to transmission time from the master to the slave station and the delay induced by the line results in the slave station signal starting 20,000 microseconds behind the master when it is operating on the low range PRR or 14,300 microseconds when operating on the high PRR. Thus for correct Loran operation the two signals should be separated by a time interval greater than the A-trace duration, the exact interval being determined by the receiver location. One signal should appear on the A-trace and one signal on the B-trace. If both fall on one trace, it shows that the normal time position with relation to the sweep has been reversed. This condition can be corrected merely by depressing the Left-Right switch and letting the signal drift across the screen until one signal is on the A-trace and one on the B-trace. Having obtained the proper



time position relationship, the signals can be halted by careful adjustment of the Station Selector switch and the Crystal Phasing control. Thus Sweep Speed position "1" gives a panoramic view of all that is taking place on that frequency.

Observation will reveal that after each main signal, a train of smaller signals will follow. These are caused by ionospheric reflection. Fig. 12 shows the pattern produced on Sweep Speed position "1". The main signal followed by its echoes is plainly visible. Each member of the train varies in magnitude independently of the others, providing a continuously unfolding picture of the changes in the ionosphere and their corresponding effect on Loran pulses. The use of a camera will permit the permanent recording of these changes so that they may be studied at a later date.

If the object is to measure the changes in the ionosphere height, a more elaborate technique is required. Normally the Loran operator is accustomed to measure the distance between signals more than 15,000 microseconds apart. The echoes from the ionosphere are rarely more than 4,000 microseconds apart. The operator positions one signal on the A-pedestal and places the B-pedestal under the slave signal which is on the B-trace. Sweep Speed positions "2", "3", and "4" are used as

vernier adjustments to this setting; the time is read from calibrated scales on Sweep Speed positions "5", "6", and "7". To measure the ionosphere time lag, the main signal is placed on the A-pedestal and the left edge of the B-pedestal is aligned with the leading edge of the echo on the A-trace. To secure alignment of the B-pedestal left edge with the left edge of the echo on the A-trace, a celluloid ruler is used to bridge the  $1\frac{1}{2}$  inch normal separation between the A-trace and B-trace on position "1". Since no signal or echo will appear on the B-pedestal, Sweep Speed positions "2", "3", and "4" are of no avail. So having secured the best possible alignment from position "1", the calibrations of Sweep Speed position "5", "6", and "7" are next used.

The time difference is read in the following manner. On Sweep Speed position "5" (see Fig. 8) 10 and 50-microsecond markers will appear. Use the B-trace as the scale and the 50-microsecond marker on the A-trace as a pointer. Count the number of 10-microsecond markers between the 50-microsecond marker on the B-trace and the first 50-microsecond marker to its right on the A-trace. Estimate to the nearest fraction of the 10-microsecond division the time lapse shown by this scale. Figure 8 shows a measurement of 25 microseconds.

Turn to Sweep Speed position "6" (see Fig. 9). Using the B-trace as a scale count the number of full 50-

microsecond spaces between the 500-microsecond marker on the B-trace and the first 500-microsecond marker to its right on the A-trace. Figure 9 shows a measurement of 300-microseconds.

Turn to Sweep Speed position "7". Count the number of 500-microsecond spaces between the first 2500-microsecond marker on the B-trace and the left edge of the B-pedestal. Only full spaces should be utilized. Figure 10 shows 3000 microseconds.

Convert the readings from positions "5", "6", and "7" to microseconds and add. The result will be the total difference in time between the arrival of main signal and the reflection from the ionosphere. (Figures 8, 9, and 10 show a time delay of 3,325 microseconds).



## DISCUSSION

During the time these observations were made, no information was available regarding the location of Loran stations. Thus the term "main signal" is used to designate the first signal received at this location, for its identity cannot be definitely determined. The work done by K. A. Norton<sup>4</sup> in synthesizing Sommerfeld's Equation<sup>5</sup> into graphical form seems to indicate that the main signal at this location may be a 1-hop E wave. Norton's graphs point out that the 2-megacycle signal which leaves the horizontal transmitting antenna with 100-KW. radiated power can be expected to maintain a ground-wave field strength of two microvolts per meter only as far as 250 miles. The project receiving location, Atlanta, Ga., is more than 250 miles from the nearest seacoast, the usual site for Loran transmitters. Even if a ten microvolt per meter signal did reach Atlanta, it is very probable that the high noise level at the Georgia Tech Campus would drown out completely the signal.

In respect to low signal strength, the use of

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<sup>4</sup>K. A. Norton, "The Propagation of Radio Waves Over the Surface of the Earth and in the Upper Atmosphere", Proc. IRE, October 1936, p. 1367.

<sup>5</sup>A. Sommerfeld, "The Propagation of Waves in Wireless Telegraphy", Ann. Phys., Vol. 28, No. 4, pp. 605, 1909.



this equipment in a fixed receiving location entailed more trouble than was normally encountered in airborne use. Whenever the received signal strength decreased, all the navigator had to do was wait a matter of minutes until the plane reached a more favorable receiving location. A change of project location was an impossibility.

Norton's analysis is corroborated by observed phenomena. During the day no signal can be heard on the 1.95-MC. channel in spite of the fact that no undue electrical disturbances are noted. No appreciable signal is detected until about a half an hour after sundown. Then in the brief space of forty-five minutes the signal strength climbs from indetectability to a value such that the gain control of the receiver may be reduced to its three-quarter range position.

With these ideas in mind it seems logical to assume that the main signal observed at this location is the first hop E reflection which J. A. Pierce describes. All following echoes would fall in the category of multi-hop E reflections, and multi-hop F reflections. Establishment of this concept provides the first tool for measuring the layer height.

The second necessary assumption is that the electron density of the ionosphere is such that it acts as a plane surface parallel to the earth and a 2-MC.

wave striking the layer will be reflected at an angle equal to its angle of incidence. This also applies to waves that enter the ionosphere, are refracted until parallel with the ionized layer, and at some later time are refracted down and out of the layer. The virtual height, the height at which the reflections appear to occur, would then be very much greater than the actual height of the layer. However, this is not an inherent fault of the receiving equipment. It is rather a problem that can be overcome only by a change in the radiated wave either in frequency or direction of propagation.

Using the assumptions that the first signal is the first hop from the E layer and that the angle of reflection is equal to the angle of incidence, it is very easy to calculate the height of the layers. The following expressions are derived in the appendix:

$$\text{HEIGHT OF E} = c \left[ \left( \frac{t_g + x}{2} \right)^2 - \left( \frac{t_g}{2} \right)^2 \right]^{\frac{1}{2}}$$

$$\text{HEIGHT OF F} = c \left[ \left( \frac{t_g + x + t_e}{2} \right)^2 - \left( \frac{t_g}{2} \right)^2 \right]^{\frac{1}{2}}$$

$$x = \left( \frac{t_e}{3} - t_g \right) + \left[ t_g^2 + \frac{4}{9} t_e^2 \right]^{\frac{1}{2}}$$

where:

$x$  = the difference in time of arrival of the ground wave and the 1-hop E wave.

$t_e$  = time difference between the arrival of the main signal and the first echo.

$t_g$  = time for ground wave to travel between transmitter and receiver.

$t_f$  = time difference between the arrival of main signal and second echo.

$c$  = velocity of propagation of radio waves.

During the period from 15 May 1947 to 20 May 1947, observations were made nightly between the hours of 8 P.M. and 12 P.M. These observations revealed that each main signal was followed by two particularly strong ionospheric echoes. The first echo arrived 1375 microseconds later than the main signal. The second echo arrived 3200 microseconds after the main signal. The first echo was visible constantly even though the magnitude varied as much as fifty percent. The second echo was not constantly visible. Its appearance was sporadic. It would disappear completely for a matter of seconds then reappear in its former location.

Explanation for such phenomenon can best be given



by using the theory of multiple hop transmission. The 1375 microseconds represent a path length difference of 256 miles. The 3200 microseconds represent a distance of 595 miles. For single hop transmission the following facts are known:

(1) The maximum path length difference between the 1-hop E wave and the ground wave occurs when the transmitter and receiver are located side by side. This difference is roughly 120 miles, twice the height of the E layer.

(2) The maximum path length difference between the 1-hop F wave and the ground wave is roughly twice the height of the F layer, 310 miles.

Neither of these figures fit both of the observed echoes. While the 1-hop F may explain the first echo, it certainly will not explain the second echo. It has been generally pointed out in the literature that the  $F_1$  and  $F_2$  layers coalesce at night to form a single F layer. Yet no mention has been found in the literature regarding the night time effect of layers other than the E and F layers on 2-megacycle sky-waves. Thus it is reasonable to assume that only the E and F layers are involved. But it has just been shown that single-hop transmissions from the E and F layers could not explain the observed data.

Multiple-hop signal transmission seems to fit the



data fairly well. It might at first be feared that for multiple hops the radiation angle would be such as to permit the signal to pierce the layer and not return. However, it must be remembered that a standard technique for measuring layer height employs a transmitter and a receiver separated by only a few hundred yards. This means that the signal must strike the layer vertically and be reflected. These signals usually have a carrier frequency of from two to four megacycles. If a signal striking the ionosphere at ninety degrees does not pierce the layer, certainly any lesser angle of incidence would not cause complete penetration at all times.

It was necessary to qualify the last statement since the density of the E layer is not constant. At times the layer is porous and permits the passage of a signal that would normally be reflected. In the next few seconds the layer becomes dense and reflects the signal. Thus sporadic F layer reflections can be noted.

The only other major problem concerning multiple-hop transmission is the matter of power loss. It has been estimated by various authorities that an eighty percent loss of power is suffered every time a reflection of the signal takes place. However, the Loran transmitter radiates 100KW. A tremendous number of reflections can conceivably take place before the signal strength will fall

below the noise level at the receiving position.

Establishment of these concepts provided some of the necessary tools for explaining the observed data. A very important feature, the transmitter location, was unknown for reasons explained below. It was assumed that the transmitter was at Charleston, S.C., approximately 290 miles from Atlanta.

The first echo could then be explained in the following way. The length of time required for 1-hop E transmission between Atlanta and Charleston is 1680 microseconds. The time required for 4-hop E transmission is 3010 microseconds. Thus the difference in time of arrival is 1350 microseconds. The observed data indicates a time difference of 1370 microseconds between the arrival of the main signal and the first echo. Thus a 4-hop E transmission path could explain the echo.

The second echo can be explained as follows. The time required for 3-hop F transmission between Atlanta and Charleston is 5070 microseconds. Thus by calculations the 1-hop E wave should arrive 3390 microseconds before the 3-hop F wave. Observed data shows the second echo arrives 3200 microseconds after the main signal.

### SUMMARY AND CONCLUSION

It must be stressed that no accurate analysis of the observed data can be made without the knowledge of the transmitter location. Only the difference in the arrival times of the two signals can be measured by the indicator. Yet this time difference is dependent on two factors: the distance to the transmitter and the configuration of the sky-wave path. Obviously any change in the transmitter location would produce a change in the sky-wave path.

The equipment developed very creditably measures the time difference of arrival of two or more radio frequency impulses. Cameras will permit continuous recordings of the change in sky-wave Loran pulses under the influence of the ionosphere. Simple equations in conjunction with observed data permit rapid calculation of ionosphere layer height as well as any changes in layer height.

The one minor draw-back seems to be the lack of information regarding Loran transmitter locations. Correlation of the receiver setting (carrier frequency), the indicator Station Selection setting (pulse repetition rate), and the geographical location of the receiver uniquely identify each particular transmitting group (master and slave stations) in a service circle roughly



4,000 miles in diameter. However, the exact location of these groups has remained somewhat of a military secret. To date no reliable information has been obtained regarding these locations.

This lack of information does not impair the use of this equipment nor does it invalidate the techniques used. Rather it points out some of the limitations which are imposed upon such a system.

The timing circuits employed were so accurate and the receiver so stable that it first appeared entirely feasible to set up a chain of ionosphere monitoring stations at very little expense. Those stations would not have to bear the brunt of maintaining a transmitter. Instead their function would be merely to gather data from Loran signals regularly being sent as part of a world wide navigation system. However calculations show that as the distance from the transmitter to the receiver increases, the difference in arrival time of sky-wave signals becomes very small. Proper resolution of signals traveling more than 300 miles requires the use of very wide band receivers.

The equipment developed is suitable to be used with a pulse transmitter at this location for the accurate determination of the layer heights.

As soon as information regarding the exact location of Loran stations is released to the public, the height of the ionosphere layers can be determined from the Loran signals.



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## APPENDIX

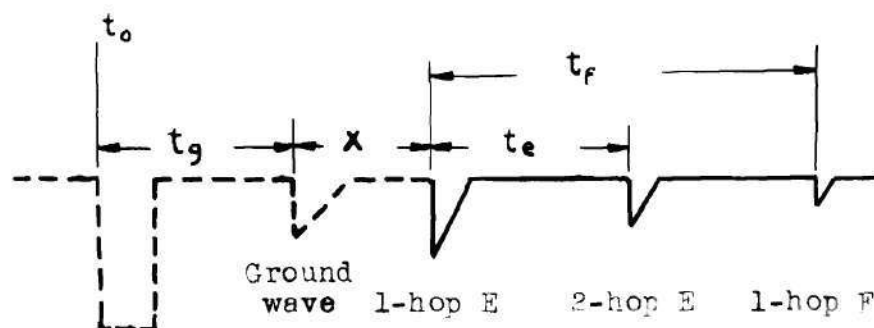


Figure 13. Time Sequence of Loran Signals

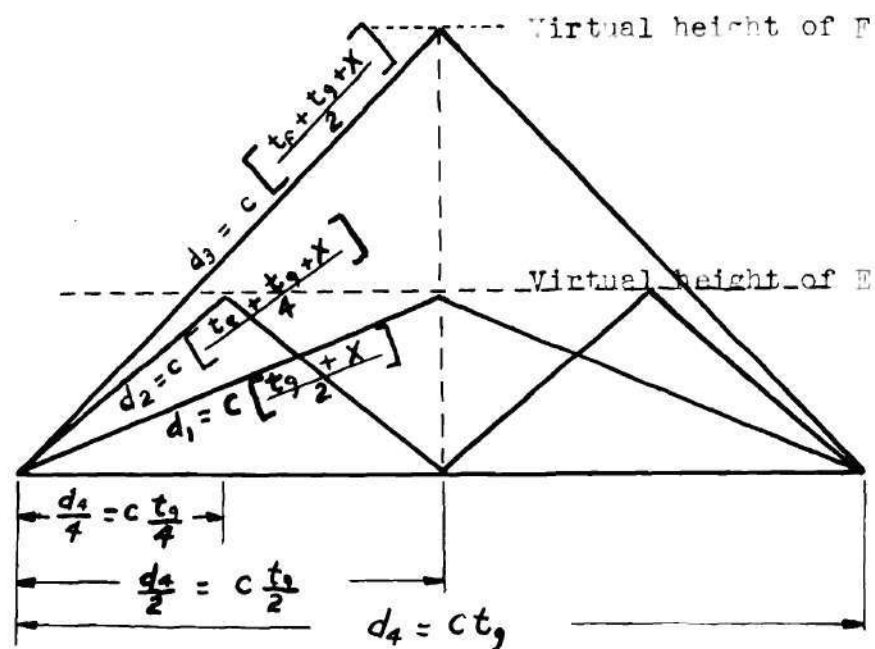


Figure 14. Sky-Wave Paths of Loran Signals

## APPENDIX

## A - Derivation of Layer Height Formulae

Figures 13 and 14 are used to develop the layer-height formulae. Figure 13 shows a time sequence of all events that transpire and defines the symbols used. The pulse on the extreme left represents the signal leaving the transmitter at  $t_0$ . The distance to the next pulse represents the time,  $t_g$ , that is required for the signal to reach the receiver via the ground wave path.  $X$  represents the difference in time of arrival of the ground wave signal and the 1-hop E sky-wave signal. Since  $t_0$ ,  $t_g$ , and  $X$  are not received at this location, they are shown dotted on the figure.

The time difference between the arrival of the 1-hop E and the 2-hop E signals is represented by  $t_e$ . Similarly, the time difference between the arrival of the 1-hop E and the 1-hop F signals is represented by  $t_f$ .

Figure 14 reduces to a time basis the events which are generally believed to occur when a signal travels from a transmitter to a receiver. This figure shows the 1-hop E, the 2-hop E, and the 1-hop F signal paths. It will be noted that the assumption is made that the virtual height of the ionosphere



layer is not dependent on the angle of incidence of the signal. It is further assumed that the layers are parallel to the earth and reflect the Loran signals at an angle equal to their angle of incidence. Thus each leg of a particular path has a length that is equal to the total time required to travel the path divided by the number of legs, i. e., the total time required to travel the 2-hop E path is  $t_g + X + t_e$ , the number of legs, 4; therefore one leg has a length  $\frac{t_g + X + t_e}{4}$

Knowing the great circle distance,  $d$ , between the transmitter and the receiver we can calculate time,  $t_g$ , from the equation  $t_g = \frac{d}{c}$ , where  $c$  equals velocity of propagation of radio waves. Finding  $t_g$  leaves only  $X$  to be determined since all other time differences are shown by the Loran Indicator.

$X$  may be found by setting up two simultaneous equations involving the height of the E layer.

$$(1a) \quad \text{HEIGHT OF E} = \left[ d_2^2 - \left( \frac{d_1}{2} \right)^2 \right]^{\frac{1}{2}}$$

$$(1b) \quad \text{HEIGHT OF E} = \left[ d_1^2 - \left( \frac{d_2}{2} \right)^2 \right]^{\frac{1}{2}}$$

SQUARING 1(a)

$$2(a) \quad (\text{HEIGHT OF } E)^2 = d_2^2 - \left(\frac{d_2}{4}\right)^2$$

SQUARING 1(b)

$$2(b) \quad (\text{HEIGHT OF } E)^2 = d_1^2 - \left(\frac{d_1}{2}\right)^2$$

EQUATING 2(a) AND 2(b)

$$3 \quad d_2^2 - \left(\frac{d_2}{4}\right)^2 = d_1^2 - \left(\frac{d_1}{2}\right)^2$$

SUBSTITUTING THE VALUES OF  $d_1$

FROM FIG. 14.

$$4 \quad c^2 \left[ \frac{t_e + t_g + x}{4} \right]^2 - c^2 \left( \frac{t_g}{4} \right)^2 = \\ c^2 \left[ \frac{t_g + x}{2} \right]^2 - c^2 \left( \frac{t_g}{2} \right)^2$$

COLLECTING TERMS

$$5 \quad x^2 + 2x \left( t_g - \frac{t_e}{3} \right) - \frac{t_e}{3} (t_e + 2t_g) = 0$$

USING THE BINOMIAL THEOREM

$$6 \quad x = \left( \frac{t_e}{3} - t_g \right) + \left[ t_g^2 + \frac{4}{9} t_e^2 \right]^{\frac{1}{2}}$$

By substituting equation (6) back into equation (1b), the virtual height of the E layer is found. The height of the F layer is given by equation (7), which is derived from Fig. 14. Since X has been previously determined, the height of the F layer is readily calculated by the use of this equation:

$$(7) \text{ HEIGHT OF F} = \left[ d_s^2 - \left( \frac{d_e}{2} \right)^2 \right]^{\frac{1}{2}}$$

Sample Calculations:

Distance between transmitter and receiver = 300 miles

Observed time difference,  $t_e = 325$  microseconds

Observed time difference,  $t_f = 555$  microseconds

$$(1) \quad t_g = \frac{d}{c}$$

$$t_g = \frac{300}{186,000} = 1610 \text{ MICROSECONDS}$$

$$(2) \quad x = \left( \frac{t_e}{2} - t_g \right) + \left( t_g^2 + \frac{1}{4} t_e^2 \right)^{\frac{1}{2}}$$

$$x = \left( \frac{325}{2} - 1610 \right) + \left( [1610]^2 + \frac{1}{4} [325]^2 \right)^{\frac{1}{2}}$$

$$x = 125 \text{ MICROSECONDS}$$

$$(3) \quad \text{HEIGHT OF E} = c \left[ \left( \frac{t_e + x}{2} \right)^2 - \left( \frac{t_e}{2} \right)^2 \right]^{\frac{1}{2}}$$

$$\text{HEIGHT OF E} = 186,000 \times 10^6 \left[ \left( \frac{1610 + 125}{2} \right)^2 - \left( \frac{1610}{2} \right)^2 \right]^{\frac{1}{2}}$$

$$\text{HEIGHT OF E} = 60 \text{ MILES}$$

$$(4) \quad \text{HEIGHT OF F} = c \left[ \left( \frac{t_f + t_e + x}{2} \right)^2 - \left( \frac{t_f}{2} \right)^2 \right]^{\frac{1}{2}}$$

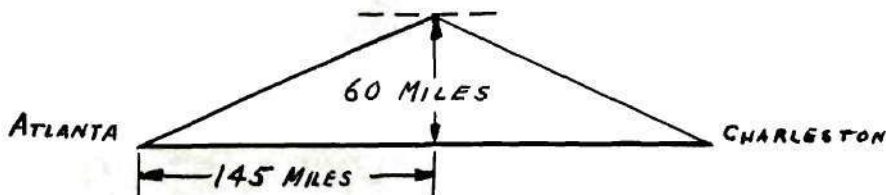
$$\text{HEIGHT OF F} = 186,000 \times 10^6 \left[ \left( \frac{1610 + 555 + 125}{2} \right)^2 - \left( \frac{1610}{2} \right)^2 \right]^{\frac{1}{2}}$$

$$\text{HEIGHT OF F} = 151 \text{ MILES}$$

## CALCULATION INVOLVING THE OBSERVED DATA

The sky-wave travel time between Charleston, S.C., and Atlanta, Ga., assuming the virtual height of the E layer to be 60 miles and the virtual height of the F layer to be 150 miles.

(1) Time for wave to travel the 1-hop E path



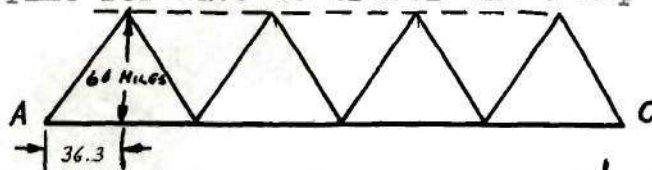
Great circle distance from Atlanta to Charleston equals 290 miles.

$$\text{Length of one leg} = [(145)^2 + (60)^2]^{\frac{1}{2}} = 156.5 \text{ miles}$$

$$\text{Length of two legs} = 313.0 \text{ miles}$$

$$\text{Time required} = 1680 \text{ microseconds}$$

(2) Time for wave to travel the 4-hop E path



$$\text{Length of one leg} = [(60)^2 + (36.3)^2]^{\frac{1}{2}} = 70 \text{ miles}$$

$$\text{Length of eight legs} = 560 \text{ miles}$$

$$\text{Time for 4-hop E} = 3010 \text{ microseconds}$$

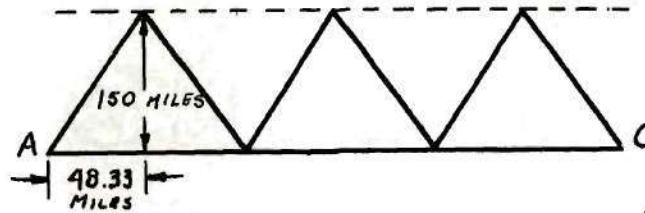
$$\text{Time for 1-hop E} = 1680 \text{ microseconds}$$

Difference in time of arrival of 1-hop E and

$$4\text{-hop E} = 1330 \text{ microseconds}$$



(3) Time for wave to travel the 3-hop F path



$$\text{Length of one leg} = \left[ (150)^2 + (48.34)^2 \right]^{\frac{1}{2}} = 157.5 \text{ mi.}$$

Length of six legs = 945 miles

Time for 3-hop F = 5070 microseconds

Time for 1-hop E = 1680 microseconds

Difference in time of arrival of 1-hop E

and 3-hop F = 3390 microseconds